



Review

Forage kochia (*Kochia prostrata*) for fall and winter grazing[☆]B.L. Waldron^{a,*}, J.-S. Eun^b, D.R. ZoBell^b, K.C. Olson^c^a USDA-ARS, Forage and Range Research Laboratory, Logan, UT 84322-6300, USA^b Department of Animal, Dairy and Veterinary Sciences, Utah State University, Logan, UT 84322-4815, USA^c Department of Animal and Range Sciences, South Dakota State University, Rapid City, SD 57702-9302, USA

ARTICLE INFO

Article history:

Available online 2 March 2010

Keywords:

Small ruminants
Fodder shrubs
Dry environment
Nutrition
Forage
Rangelands

ABSTRACT

Forage kochia (*Kochia prostrata* (L.) Schrad.), also known as prostrate kochia, or prostrate summer cypress is a long-lived, perennial, semi-evergreen, half-shrub well adapted to the temperate, semiarid and arid regions of central Asia and the western U.S. In these areas it has proven to be a valuable forage plant for sheep, goats, camels, cattle, and horses. Forage kochia is a C₄ plant that is extremely drought and heat tolerant, in part due to a taproot that can extend up to 6.5 m in depth. It is also very salt tolerant and well adapted to some ecosystems dominated by halophytic species. It has been reported to be very productive when grown in soils with salinity electrical conductivity (EC) levels approaching 20 dS/m, and capable of persisting at much higher EC levels. Forage kochia's biomass yield depends upon the subspecies and environment, but reports generally range from 1000 to 1800 kg/ha in environments receiving 100–200 mm annual precipitation. Studies and practical experience have shown that forage kochia is very palatable and nutritious, especially during the late summer through winter period. Its nutritional characteristics include fall and winter crude protein levels above 70 g/kg needed for gestating ruminants. It also has low tannins and oxalates, and has not been reported to be a nitrate accumulator. When fed alone, it has acceptable fiber qualities, but research has shown that it can improve digestion kinetics when in a mixed diet with the low quality grasses as is common during late summer, fall, and winter months. Overall, forage kochia has the potential to improve the sustainability of small ruminant production in semiarid regions that frequently experience extended drought and saline conditions.

Published by Elsevier B.V.

1. Introduction

Forage kochia (*Kochia prostrata* [L.] Schrad.) (synonym = *Bassia prostrata* [L.] A.J. Scott) is a perennial, semi-shrub, native to the heavily grazed arid and semiarid rangeland regions of Central Eurasia, and more recently introduced to western U.S. rangelands (Harrison et al., 2000). It has been shown that forage kochia is broadly

adapted to various semiarid rangelands (McArthur et al., 1996; Harrison et al., 2000), has high salt and alkali tolerance (Francois, 1976; Romo and Haferkamp, 1987), is competitive against the annual noxious weeds cheatgrass (*Bromus tectorum* L.) and halogeton (*Halogeton glomeratus* [Stephen ex Bieb.] C.A. Mey.) (McArthur et al., 1990; Stevens and McArthur, 1990; Monaco et al., 2003) and is one of few species that can be successfully established on severely degraded, frequently burned, cheatgrass-infested rangelands (Monaco et al., 2003; Newhall et al., 2004).

The literature suggests that forage kochia is most abundant in the countries of Kazakhstan, Uzbekistan, and Kirghistan, where for nearly a century it has been recognized as an important fall and winter forage for sheep, cattle, horses, camels, and wildlife (Balyan, 1972; Waldron

[☆] This paper is part of the special issue entitled: Potential use of halophytes and other salt-tolerant plants in sheep and goat feeding, Guest Edited by Hichem Ben-Salem and Pierre Morand-Fehr.

* Corresponding author. Tel.: +1 435 797 3073; fax: +1 435 797 3075.
E-mail address: blair.waldron@ars.usda.gov (B.L. Waldron).

et al., 2001, 2005; Gintzburger et al., 2003). Nechaeva (1985) stated that forage kochia is a good fattening feed that is readily grazed by sheep and cattle and overall is one of the most palatable and nutritive forage species in the arid zones of central Asia. In Uzbekistan, it is known as 'the alfalfa of the desert' (Waldron et al., 2005), in reference to its value as a forage for ruminants. Over five decades ago, Larin (1956) stated that the "Kazaks esteem it (forage kochia) as fattening feed for sheep, goats, and camels." More recently, Alimov and Amirkhanov (1980) referred to forage kochia as an especially desirable sheep forage that is 'preferred' for improving the winter desert pastures of Kazakhstan. Likewise, in the country of Iran, forage kochia is recognized for its higher forage value and palatability as compared to other common shrubs (Nemati, 1977).

In relation to livestock performance, forage kochia has been esteemed for its ability to provide relatively large amounts of biomass, protein, carotene, phosphorous, and calcium to grazing animals in temperate, dry ecosystems (Balyan, 1972; Davis, 1979; Gintzburger et al., 2003). In the U.S., Waldron et al. (2006) recently documented that cattle grazing forage kochia during the fall and winter maintained or improved body condition without any additional protein or nutrient supplementation. Its desirable nutritive properties include high crude protein (CP) (>70 g/kg) during the critical fall/winter grazing period (Davis, 1979; Davis and Welch, 1985; McKell et al., 1990; Waldron et al., 2006), low non-toxic levels of oxalates (Davis, 1979), acceptable digestibility (Welch and Davis, 1984; Davis and Welch, 1985; McKell et al., 1990; Waldron et al., 2006), and increased rate of dry matter (DM) and fiber digestion when mixed with a low quality forage (Stonecipher et al., 2004; Wall et al., 2006).

Ben Salem and Smith (2008) reported that shrubs adapted to harsh, semiarid environments may provide needed solutions to the lack of available forage for ruminants on these rangelands. In this respect, forage kochia has potential to become even more important to small ruminant production throughout the world, especially in dry, saline regions, where there are efforts to increase or provide more stable forage production. In this paper, we discuss forage kochia's wide adaptation to arid and semiarid rangelands, tolerance to saline/alkaline environments, and nutritional and forage value. In addition, this article reviews livestock responses from experimental studies of confined cattle fed or grazing forage kochia, and a possible mechanism by which forage kochia improves nutrient utilization.

2. Forage kochia and its adaptation to arid and semiarid rangelands

Forage kochia (*K. prostrata*), sometimes called prostrate kochia, prostrate summer cypress, or local names of izen (Uzbekistan) and prutnyak (Russia) is a long-lived, perennial, semi-evergreen, half-shrub well adapted to semiarid, arid, alkaline, and saline rangelands and steppes (Harrison et al., 2000; Gintzburger et al., 2003). Forage kochia's native distribution ranges from central Europe to the west, Siberia in the north, Afghanistan and Asia Minor in the south, and east to China, Mongolia, and Tibet (Balyan, 1972). Forage

kochia was introduced to North America in the early 1960s where it has proven to be well adapted to the temperate, semiarid rangelands of western U.S. (Harrison et al., 2000). Forage kochia is found growing naturally on soils ranging from sandy to heavy clay and from elevations of 0 to 2400 m (Balyan, 1972). Forage kochia has a perennial woody base with yearly herbaceous growth that can reach heights ranging from 30 to 75 cm, depending upon the ecotype and annual precipitation (Gintzburger et al., 2003). Its drought tolerance and persistence are in part due to a thick, woody root system that penetrates to depths of 3–6.5 m depending upon soil type (Gintzburger et al., 2003), and lateral roots stretching 130–160 cm that mine for moisture in the upper soil layers (Balyan, 1972). It begins flowering in July and will continue to flower for 65–85 days. Seed ripening begins in late September and is completed by mid-October to late November, depending upon variety and/or cultivar (Waller et al., 1983; Kashkarov and Balyan, 1989; Waldron et al., 2005).

2.1. Subspecies and ecotypes of forage kochia

Forage kochia is a distant relative of annual kochia (*Kochia scoparia* L.) and gray or green molly (*Kochia americana* S. Wats) (North American native equivalent to *K. prostrata*), with recent research showing that these three species of *Kochia* are genomically distinct and lack the ability to cross hybridize (Lee et al., 2005). *K. prostrata* and *K. scoparia* are both sometimes referred to as 'forage kochia' and 'summer cypress'; however, *K. prostrata* differs in that it has a perennial growth habit, does not spread into perennial plant stands, and is not known to contain toxic levels of nitrates or oxalates (Harrison et al., 2000).

Forage kochia (*K. prostrata*) is a complex species within the *Chenopodiaceae* family represented by three known ploidy levels (2 \times , 4 \times , and 6 \times) (Balyan, 1972; Pope and McArthur, 1977; Shakhnov and Sagimbaev, 1982; Rubtsov et al., 1989) and multiple subspecies and ecotypes (Balyan, 1972; Gintzburger et al., 2003; Waldron et al., 2005). Balyan (1972) and Gintzburger et al. (2003) refer to the two subspecies of *virescens* ([Frenzl.] Prat.) (green type) and *grisea* (Prat.) (gray type) with the major distinguishing feature being the relative amount of pubescence (*grisea* being more pubescent and *virescens* being more glabrous). Within the subspecies *grisea*, two varieties *canescens* and *villosissima* are often recognized; however, some researchers refer to these as two distinct subspecies (Waldron et al., 2005).

Most literature from the former U.S.S.R. and its republics refers to the 'clay', 'sandy', and 'stony' (synonymous with 'mountain') ecotypes or varieties of forage kochia, with these designations based upon differences in ecological adaptation and resulting area of cultivation in its native environment (Balyan, 1972; Gintzburger et al., 2003; Waldron et al., 2005). The clay ecotype is often synonymous with subspecies *virescens* (Nechaeva, 1985) and is usually characterized as having less pubescence, shorter stature, and finer stems than *grisea*. These stems turn bright red during seed ripening. It is best adapted to heavier clay, silt soils of semiarid steppe regions (Balyan, 1972; Gintzburger et al., 2003). Uzbek researchers believe that subspecies *virescens* is the most preferred by livestock (Waldron et al.,

2005); however, recent research indicated that there was no difference in cattle preference between large statured types of *virescens* and *grisea* (Davenport, 2005). The sandy ecotype is often used to describe subspecies *grisea* variety *villosissima* (Nechaeva, 1985; Waldron et al., 2005), is characterized as having dense, white, hairy-like pubescence, and grows best on sandy-desert, semiarid soils (Balyan, 1972; Gintzburger et al., 2003; Waldron et al., 2005). The stony ecotype is often synonymous with subspecies *grisea* variety *canescens* (Nechaeva, 1985; Waldron et al., 2005), is also characterized by dense pubescence on the stem, and is reported to be more adapted to calcareous, rocky slopes (Balyan, 1972; Gintzburger et al., 2003; Waldron et al., 2005).

2.2. Forage kochia's drought and salinity tolerance

Forage kochia is generally considered to be highly drought and saline tolerant (Balyan, 1972; Gintzburger et al., 2003). This is largely based upon its ability to establish and produce edible forage in dry, saline environments where many other species either fail to establish or do not persist (Balyan, 1972; Durikov, 1986; Monaco et al., 2003; Newhall et al., 2004). Because of its drought and salinity tolerance, much of the forage kochia research in the U.S. has been conducted on its adaptation to salt desert shrub ecosystems of the western U.S. Salt desert shrublands are characterized as having lower elevations, more arid conditions, more saline/sodic, finer-textured soils, with slower infiltration rates, as compared to the *Artemisia*-dominated ecosystems in the western U.S. (West, 1983). Dominant vegetation typical of these ecosystems includes shadscale saltbush (*Atriplex confertifolia* [Torr. & Frém.] S. Watson), spiny hopsage (*Grayia spinosa* [Hook.] Moq.), bud sagebrush (*Picrothamnus desertorum* Nutt.), black greasewood (*Sarcobatus vermiculatus* [Hook.] Torr.), salt grass (*Distichlis spicata* [L.] Greene), iodine bush (*Allenrolfea occidentalis* [S. Watson] Kuntze), and pickleweed (*Salicornia europaea* L. ssp. *rubra* [A. Nelson] Breitung) (West, 1983). In recent decades, these ecosystems have received much attention due to repeated wildfires, fueled by the invasive annual cheatgrass (*B. tectorum*), that has destroyed existing native shrubs and promoted dominant monocultures of cheatgrass (Harrison et al., 2002).

Newhall et al. (2004) reported that forage kochia was one of few species capable of establishing and competing with cheatgrass in a salt desert shrub environment where repeated wildfires, severe wind erosion of topsoil, and drought (annual precipitation of 140 mm) had denuded the landscape. Monaco et al. (2003) conducted forage kochia research in a similar environment that historically had been used for winter grazing of sheep, but where overgrazing and repeated wildfires had completely eliminated all perennial shrubs leaving only a monoculture of cheatgrass. They reported that forage kochia established, persisted, and reduced the frequency of cheatgrass during a 10 year period with annual precipitation ranging from 127 to 200 mm. McArthur et al. (1996) evaluated both *virescens* and *grisea* type of forage kochia on a sodic, saline site that received 152–203 mm of annual precipitation. They reported that both subspecies were well adapted to this harsh site with

only 5% mortality of forage kochia plants after four years of growth (McArthur et al., 1996). Furthermore, Stevens and McArthur (1990) reported successful establishment of forage kochia on low-laying, harsh salt desert sites previously dominated by greasewood (*S. vermiculatus*) and in alkali playas dominated by the invasive, poisonous annual forb halogeton (*Halogeton glomeratus*). Forage kochia not only successfully established, but also eliminated halogeton on these alkaline soils (Stevens and McArthur, 1990).

Several studies have attempted to quantify forage kochia's salt tolerance. Francois (1976) reported that forage kochia was highly salt tolerant and still produced abundant forage when grown in soils with EC levels ranging up to 17 dS/m. The author further reported that although the sodium and chloride content within the plants approached 50 and 80 cmol/kg of plant DM, there were no visible salt injury symptoms (Francois, 1976). Additional studies have shown that forage kochia established and had a high survival when grown in oil well reserve pits (contaminated with dried drilling fluids) with EC levels ranging from 23 to 93 dS/m (McFarland et al., 1990), and when planted in unleached, processed oil shale with EC levels of 13 and 18 dS/m (Frischknecht and Ferguson, 1984; McKell, 1986). Recent research by the senior author (unpublished data) confirmed Francois (1976) suggestion that variation for salt tolerance exists within forage kochia with subspecies *grisea* having higher salt tolerance than subspecies *virescens*.

2.3. Development and cultivation of forage kochia

The potential of forage kochia to improve the forage production of semiarid rangelands was recognized soon after the turn of the 20th century with the first cultivation of forage kochia in Uzbekistan and Kazakhstan in the early 1930s (Alimov and Amirkhanov, 1980; Rabbimov, 1984). Breeding and development of improved cultivars appear to have begun as early as the 1970s in the U.S.S.R. (Alimov and Amirkhanov, 1980; Rabbimov, 1984). Several researchers (Herbel et al., 1981; Nechaeva, 1985; P'yankov et al., 1988) mentioned improved cultivars of forage kochia that were available in the former Soviet Union republics during the 1980s. Waldron et al. (2005) found some remnant seed of Uzbek-originated cultivars; however, it is not likely that these are commercially available at this time. Krylova (1988) and Harrison et al. (2000) independently reviewed the introduction, cultivar development, and cultivation of forage kochia in the U.S. Forage kochia was first introduced to the U.S. in 1966 by researchers looking for a plant to suppress halogeton on droughty and saline soils (Harrison et al., 2000). One germplasm accession (PI 314929) was selected and released as the cultivar 'Immigrant' in 1984 based upon its overall persistence, forage production, forage quality, palatability, and competitiveness with annual weeds (Stevens et al., 1985). Immigrant remains the only released cultivar of forage kochia in the U.S., and is a short-statured, diploid, subsp. *virescens* type used for livestock and wildlife forage, soil stabilization, rangeland reclamation, and suppression of wildfires (Stevens et al., 1985; Harrison et al., 2000, 2002; Waldron et al., 2006). An active forage kochia research and breeding program is led by the senior author of this article with the goal of developing

larger statured, more productive cultivars to enhance its utilization as a winter forage in the temperate, deserts of the western U.S. (Waldron et al., 2001, 2005). Because of its competitive nature, some people have worried about forage kochia invading and suppressing native plant populations in the U.S. (Clements et al., 1997; Harrison et al., 2000). However, several researchers have reported that immigrant forage kochia competes well with annuals, but does not invade perennial plant communities (Pendleton et al., 1992; Harrison et al., 2000; Monaco et al., 2003).

The successful establishment of forage kochia is greatly dependent upon its peculiar seed biology. Hence many studies have been conducted to examine seed harvest, germination, and planting of forage kochia (Balyan, 1972; Young et al., 1981; Waller et al., 1983; Stevens and Van Epps, 1984; Haferkamp et al., 1990; Stewart et al., 2001; Kitchen and Monsen, 2001; Monaco et al., 2003). In brief, the most reliable establishment comes from broadcast plantings (as opposed to drilling) done during the months of December through February (as opposed to spring plantings) using freshly harvested forage kochia seed (as opposed to seed one year or older). These recommendations are the result of forage kochia's inability to emerge from depths greater than 1 cm, rapid loss of seed viability under normal storage conditions, and delayed, asynchronous germination of fresh seed. These appear to be adaptive traits that have evolved enabling forage kochia propagation in the wild.

Larin (1956) described forage kochia as one of the most drought tolerant and desirable species within the *Chenopodiaceae* family. Hence, forage kochia has frequently been recommended for improving productivity of semiarid and arid rangelands in central Asia and Iran (Larin, 1956; Balyan, 1972; Alimov and Amirkhanov, 1980; Rabbimov, 1984; Nechaeva, 1985; Nemati, 1986; Kashkarov and Balyan, 1989; Gintzburger et al., 2003; Zadbar et al., 2007). Forage kochia's forage yield potential varies depending upon the subspecies and environment it is grown in, but generally yield reports range from 1000 to 1800 kg/ha (Balyan, 1972; Nechaeva, 1985; Kashkarov and Balyan, 1989; Gintzburger et al., 2003; Waldron et al., 2005, 2006). However, at least two studies reported much higher forage yields of approximately 2000 and 6000 kg/ha (Lachko, 1987; Durkov, 1990). In almost all cases, the reported yields represent at least a three- to fivefold increase in forage production as compared to existing vegetation not comprised of forage kochia (Balyan, 1972; Nechaeva, 1985; Kashkarov and Balyan, 1989; Gintzburger et al., 2003; Waldron et al., 2006), and sometimes even higher than 10-fold production increase (Koch and Asay, 2002). Forage kochia exhibits C_4 photosynthesis (Pyankov et al., 2001), and as typical of C_4 species, is very tolerant of high heat with greater than 60% of its current year's growth accumulating after June in temperate, semiarid regions (Balyan, 1972).

3. Nutritional quality

The USDA-ARS has intensively investigated agronomic characteristics of perennial forage kochia since the 1960s, whereas its nutritional characteristics as a forage source for livestock production, has been examined beginning in

the late 1970s. Nevertheless, very limited information is available in the literature relative to nutritional aspects of forage kochia.

3.1. Protein, carbohydrate, and in vitro digestibility

Davis (1979) reported that CP content of forage kochia was comparable to winterfat (*Krascheninnikovia lanata* [Pursh] A. Meeuse & A. Smit) (synonym, *Eurotia lanata*), Iranian saltbush (*Atriplex verrucifera* Bieb.), and fourwing saltbush (*Atriplex canescens* [Pursh] Nutt.), but that crude fiber levels were much higher in forage kochia in March than in the other shrubs. In that study, forage kochia CP declined from 147 g/kg in August to 89 g/kg in March due to natural weathering (Davis, 1979). Similarly, Koch and Asay (2002) reported that while CP content of forage kochia was higher than that of legumes [alfalfa (*Medicago sativa* L.), sainfoin (*Onobrychis viciaefolia* Scop.), and cicer milkvetch (*Astragalus cicer* L.)], or grasses [wildrye (*Elymus* spp.) and wheatgrass (*Agropyron* spp.)], it also declined from 95 g/kg in November to 77 g/kg in February as a result of weathering.

Waldron et al. (2006) compared nutritional quality in a forage kochia-crested wheatgrass pasture grazed from November through January by mature beef cows. It was determined that forage kochia had higher CP but lower *in vitro* DM digestibility (IVDMD) when compared to crested wheatgrass throughout the study (Table 1). Forage quality of both forage kochia and crested wheatgrass decreased as the winter progressed, with a decrease in CP but an increase in neutral detergent fiber (NDF). This change was due to both natural weathering and selective grazing. The initial CP level for forage kochia was above the 70 g/kg requirement for late-gestation beef cattle (NRC, 1996), but after one month of grazing, the CP level in residual forage kochia fell below this minimum level (Table 1). The increased NDF and decreased IVDMD of forage kochia indicated that forage intake and digestion would be compromised due to the obvious decline in its forage quality. McKell et al. (1990) reported similar results wherein CP levels in a forage kochia-crested wheatgrass pasture fell from approximately 90–55 g/kg after 13 days of confined grazing by sheep. However, McKell et al. (1990) and Waldron et al. (2006) reported that contents from diet samples actually consumed by grazing animals were higher in CP and digestibility than in the total available biomass, meeting minimum ruminant requirements. Consequently, as long as grazing ruminants are allowed adequate selectivity so forage kochia is actually included in their diets, CP content should remain adequate. Interestingly, McKell et al. (1990) found that a difference in foraging experiences of lambs and range ewes appeared to be responsible for forage selection, resulting in a more dramatic decrease in CP content of forage kochia by experienced animals.

McKell et al. (1990) reported that forage kochia contained less woody stems and had lower lignin content than that of winterfat. This may allow greater opportunities for grazing animals to select a more nutritious diet on forage kochia pastures as compared to other common range shrubs. Cook et al. (1953) reported that sheep tended to preferentially graze tender stems and leaves of available

Table 1

Comparison of nutritional quality between forage kochia (FK) and crested wheatgrass (CWG) pastures grazed by mature beef cows during the fall and winter of 2003 and 2004.

Trait	Harvest month					
	November		December		January	
	FK	CWG	FK	CWG	FK	CWG
CP (g/kg)	96.2 a, x	53.4 a, y	57.5 b, x	39.0 b, y	47.9 b, x	37.7 c, y
NDF (g/kg)	555 c, y	608 c, x	634 b, x	627 b, x	667 a, x	654 a, x
IVDMD (g/kg)	539 a, y	650 a, x	445 b, y	654 a, x	393 c, y	583 b, x

Source: Waldron et al. (2006).

CP, crude protein; NDF, neutral detergent fiber; IVDMD, *in vitro* dry matter digestibility.

^{a,b,c} Means across rows within trait with different letters indicate difference between months ($P < 0.05$).

^{x,y} Means across rows within month with different letters indicate difference between species ($P < 0.05$).

shrubs, and in their study reduced CP levels of remaining shrub biomass from 10 to 6 g/kg. Similar results might be expected for sheep grazing forage kochia, as Nechaeva (1985) reported that sheep preferred to eat the thin shoots and leaves of forage kochia. Davenport (2005) observed that cattle selectively grazed portions of forage kochia stems containing seeds, and then went on to graze upper stems and leaves. Davis and Welch (1985) found that during November, upper seed-bearing forage kochia stems had higher levels of CP (107 g/kg) than the remaining lower, leaf-bearing part of the stems (86 g/kg). In accordance with these results, Waldron et al. (2006) observed a dramatic difference in CP values of 191, 123, and 55 g/kg for seed, leaves, and stems, respectively, and a similar reduction in IVDMD, with IVDMD of forage kochia stems being 43% less than seeds. Therefore, preferential grazing and a relative declining proportion of quality from seeds to lower stems must account for the reduction in forage quality of available forage kochia. In terms of management considerations, grazing ruminants should be moved to new pastures or drylots when residual forage of forage kochia-grass pastures reaches 60–65% utilization to ensure that diet quality does not fall below maintenance requirements (Waldron et al., 2006).

Davenport (2005) compared 24 experimental lines of forage kochia, and reported that October contents of CP, NDF and IVDMD were 99, 544 and 569 g/kg, respectively, on average over two years. These values further confirm that forage kochia is an excellent fall and winter forage because it exceeds minimum levels of CP and digestibility. However, this study also clearly indicated that there is a large variation in nutrient composition among accessions and subspecies of forage kochia; for instance, CP content ranged from 122 to 72 g/kg. Davenport (2005) concluded that these CP levels were all above minimum nutritional requirements, and thus CP was only moderately associated with forage kochia preference by grazing animals.

3.2. Potential anti-nutritive factors

Annual kochia (*K. scoparia*), a relative of forage kochia, is known to contain several potential toxicants, including oxalates, nitrates, saponins, alkaloids, and a disease syndrome called polioencephalomalacia (Burrows and Tyril, 2001). The limited research on potential anti-nutritive components in forage kochia is discussed in this sec-

tion, and overall indicates that forage kochia does not contain the toxicants common to annual kochia. Further research on potential toxicants and other secondary chemical compounds, such as terpenes and alkaloids, is needed in relation to how they may affect nutritional value of forage kochia.

Oxalates react with calcium to produce insoluble calcium oxalate, reducing calcium absorption. This leads to a disturbance in the absorbed calcium:phosphorus ratio, resulting in mobilization of bone mineral to alleviate the hypocalcemia (Allison et al., 1981). Cattle and sheep are less affected because of degradation of oxalate in the rumen (Allison et al., 1981). However, cattle mortalities from oxalate poisoning due to acute hypocalcemia have occurred on *Setaria* pastures (Jones et al., 1970), and sheep have been poisoned while grazing buffelgrass (*Pennisetum ciliare* [L.] Link) (McKenzie et al., 1988). Davis (1979) reported that oxalate levels in 13 accessions of forage kochia were less than 22 g/kg, which is lower than the critical levels reported by Morton et al. (1959). Additionally, oxalate levels were lower in forage kochia accessions than in fourwing saltbush and winterfat accessions (Davis, 1979). The authors of this article sampled forage kochia from several states in the western U.S. during June through September and found only low, non-toxic levels of oxalates (unpublished data). Thus, there is no indication that oxalate content of forage kochia would be detrimental to livestock.

Accumulation of nitrate in forage plants can pose serious health problems for ruminant livestock (Murphy and Smith, 1967; Burrows et al., 1987). Normally nitrate is absorbed and rapidly assimilated with little hazard to foraging ruminants. However, under certain circumstances some plants may accumulate toxic concentrations of nitrate (Clay et al., 1976; Haliburton and Edwards, 1978). Although nitrate accumulation has been observed in annual kochia (*K. scoparia*), it has not been reported for perennial forage kochia (Harrison et al., 2000; Koch and Asay, 2002). The authors of this article determined that forage kochia samples collected from Utah, Wyoming, Nevada, and Oregon during the summer months did not contain toxic levels of nitrates (unpublished data). Most recently, Leonard et al. (2008) reported that nitrate uptake by forage kochia was low compared to cheatgrass and crested wheatgrass, which suggests that forage kochia does not intensely compete for soil nitrate with these herbaceous species that

have fibrous root systems, and probably does not pose a nitrate toxicity threat.

Tannins are naturally occurring plant polyphenols that can have a large influence on the nutritive value of forages. Tannins in forage have both negative and positive effects on nutritive value; tannins in high concentrations reduce intake, digestibility of protein and carbohydrates and animal performance, whereas tannins in low to moderate concentrations prevent bloat and increase the flow of non-ammonia N and essential amino acids from the rumen (Reed, 1995). Davis (1979) reported that in 13 accessions of forage kochia, tannin content was 5.9 mg/g on average during the browse utilization season of August–March, and the content was much lower than the critical level (more than 25 mg/g) that inhibits animal acceptance (Donnelly and Anthony, 1969). The low content of tannins in forage kochia warrants little concern on the negative effect of tannins to grazing ruminants.

4. Stimulatory effects on forage intake and nutrient digestion

Dormant grasses are deficient in CP (<70 g/kg, Van Soest, 1994) and high in cell wall components, while dormant forage kochia has higher CP levels (generally >70 g/kg) and lower cell wall components. Mixtures have potential to exhibit a positive associative effect (Merchen, 1993; DelCurto and Olson, 2000) wherein one feedstuff increases the digestibility and/or intake of another above what the additive effect would be (Merchen, 1993). Positive associative effects can be seen with a mixture of high fiber and high protein forages (Merchen, 1993). Increased protein stimulates microbial growth, which causes more rapid fermentation of fiber in feedstuffs, resulting in more energy released for the host ruminant animal (Hess et al., 1994). This typically enables ruminants to increase nutrient intake from dormant grass when higher CP feedstuffs like forage kochia are added to the diet (Merchen, 1993).

4.1. Grazing animal responses

Gade and Provenza (1986) reported that sheep on pastures containing both crested wheatgrass and shrubs (mixture of forage kochia, fourwing saltbush, antelope bitterbrush (*Purshia tridentata* [Pursh] DC.), big sagebrush (*Artemisia tridentata* L.), rubber rabbitbrush (*Ericameria nauseosa* [Pall. ex Pursh] G.L. Nesom & Baird) (synonym = *Chrysothamnus nauseosus*), and winterfat) ate diets with an average CP level of 81 g/kg, while those on pastures containing only crested wheatgrass consumed diets with 56 g/kg CP on average. Organic matter intake for sheep grazing pastures with crested wheatgrass and shrubs was also higher, especially after snow accumulation (Gade and Provenza, 1986). Waldron et al. (2006) showed that cattle grazing a mixed stand of forage kochia and crested wheatgrass during winter were able to select a diet that was higher in nutritional value than the average of available forage.

4.2. Responses from experimental studies using confined cattle

Metabolism experiments have been conducted to evaluate nutritional response of cattle to increasing levels of forage kochia mixed in diets of low quality grass (Stonecipher et al., 2004; Wall et al., 2006). In these studies, forage kochia harvested like hay, and tall wheatgrass (*Thinopyrum ponticum* [Podp.] Z.-W. Liu & R.-C. Wang) straw (residue after seed harvest) were used to mimic the forage resources that would be available to grazing ruminants during fall and winter. Stonecipher et al. (2004) assessed intake and digestibility of forage kochia fed at varying dietary ratios (0 to 75%) with tall wheatgrass straw. They reported that DM intake increased linearly, NDF digestibility decreased linearly, and there was no change in overall DM digestibility as the proportion of kochia increased in the diet. Digestibility of DM and NDF responses may have differed because forage kochia contained a higher concentration of cell solubles than wheatgrass (NDF content of 53.8% and 77.7% for kochia and wheatgrass, respectively), such that digestion of more cell solubles offset decreasing digestion of cell walls as forage kochia increased in the diet.

In contrast, *in situ* rate of DM and NDF digestion of wheatgrass and of the forage kochia linearly increased ($P < 0.05$, except forage kochia NDF digestion with $P = 0.06$) as the proportion of kochia increased in the diet. Particulate passage rate also increased linearly ($P < 0.001$) as forage kochia increased in the diet, with a concomitant reduction ($P < 0.001$) in GI tract particulate residence time (Stonecipher et al., 2004; Wall et al., 2006). Shrubs, like forage kochia, have thinner cell walls with a greater cell soluble fraction than grasses, such as tall wheatgrass (Van Soest, 1994). Thinner cell walls are reduced to small particles more rapidly, allowing particles to pass more quickly from the rumen and consequently resulting in more rapid passage rates. Additionally, increased CP levels above the microbial requirement of 70 g/kg by adding more forage kochia apparently stimulated microbial growth, allowing microbes to ferment the forages more rapidly, which caused more rapid particle size reduction and increased passage rate (Hess et al., 1994). Extent of fiber (NDF) digestion likely decreased because rates of NDF digestion and passage rate increased, thus reducing ruminal residence time and extent of fermentation (Van Soest, 1994). Shrub cell walls can be thinner because they are more highly lignified, which may further contribute to reducing cell wall (NDF) extent of digestion. Although extent of fiber (NDF) digestion decreased as more forage kochia was added to the diet, the steers were able to increase feed intake because of the increase in the rate of digestion of DM and NDF. Forage intake is positively related to rate as well as extent of digestion in the rumen (Forbes, 1996). In addition to the fact that forage kochia has been considered a potential source of forage that has the ability to increase CP supplied to livestock in the winter grazing period, it can also increase digestibility of low quality forage. Therefore, it is likely that grazing ruminants wintered on low quality forages may increase their intake, digestion, and nutritional status by consuming forage kochia, contributing to positive

Table 2

Comparison of performance of mature beef cows grazing forage kochia-grass pastures or fed alfalfa hay in drylot during the fall and winter of 2003 and 2004.

Treatment	Body weight (kg)			Body condition score			Backfat thickness (cm)		
	Initial	Final	Gain	Initial	Final	Gain	Initial	Final	Change
Drylot	609 b	658 a	45	4.9 b	5.8 a	0.9	0.8 b	1.1 a	0.3 x
Pasture	621	639	19	4.9 b	5.2 a	0.3	0.9	0.7	−0.2 y

Source: Waldron et al. (2006).

Body condition score was determined visually by an experienced observer using a range from 1 to 9, where 1 equaled emaciated and 9 was obese (Wagner et al., 1988); backfat thickness was measured using a portable ultrasound (Model SSC-210Vet; Aloka, Wallingford, CT, USA).

^{a,b}Means of initial and final values within a treatment with different letters indicate difference ($P < 0.05$).

^{x,y}Means of drylot and pasture change values within a trait with different letters indicate difference ($P < 0.05$).

animal performance while simultaneously reducing winter feed cost.

5. Livestock performance

A number of studies have shown that livestock lose body weight (BW), body condition score (BCS) and backfat thickness (BFT), and they are not in optimum condition for parturition when wintered on stockpiles grass without supplementation (Knipfel, 1977; Cochran et al., 1986; Willms et al., 1993; Adams et al., 1994; Villalobos et al., 1997; Freeze et al., 1999). While supplementation of the stockpiled grass with high protein sources can improve animal performance, this can be labor intensive and costly (Cochran et al., 1986; Adams et al., 1994; Villalobos et al., 1997; Freeze et al., 1999; McCartney et al., 2004). Alternatively, some rangeland shrubs have been shown to meet ruminant protein requirements during the fall and winter and may act synergistically in mixes with grasses where the grass component overcomes the shrub's lack of digestible energy (Cook, 1972; Otsyina et al., 1982; Gade and Provenza, 1986; Ben Salem and Smith, 2008).

Koch and Asay (2002) performed a grazing study using 280 beef cows on forage kochia pasture. Cows grazed from early January until mid-March, a period in which there were 25 cm of snow cover. A seed crop had been harvested the previous fall, leaving most of the forage kochia below the snow. The cows were given a high-energy grain supplement (130 g/kg CP) at 0.9 kg/day for two weeks due to unusual cold weather, and their BCS increased from 4.5 to 6.5 (on a scale of 1–9) (Wagner et al., 1988) from early January to early March with the forage kochia grazing. The cows calved in late March and early April. Forage kochia near the end of the grazing period still contained over 75 g/kg CP. Although it appeared unpalatable, cows readily consumed forage kochia and maintained adequate physiological condition for parturition.

Waldron et al. (2006) evaluated livestock performance using forage kochia-grass pastures as a resource to extend cattle grazing into the fall and winter as compared to a traditional harvested alfalfa hay winter feeding program. Averaged over two fall-winter periods, change in BW and BCS did not differ between cattle on forage kochia-grass pastures vs. drylot alfalfa-fed cattle (Table 2). Cows grazing forage kochia and crested wheatgrass maintained BW and improved BCS. The final BCS of 5.2 for cows grazing forage kochia was considered optimum condition for these cattle as they entered parturition, and the final BFT of

pasture-fed cows of 0.7 cm was still greater than 0.5–0.6 cm recommended for overwintering cows (Freeze et al., 1999). Though, pasture- vs. drylot-fed cows did not differ with regard to gain in BW and BCS, drylot-fed cows did have a greater change in BFT than those on pasture (Table 2). The favorable performance of gestating beef cows grazing forage kochia pastures during the fall and winter period suggest that forage kochia provides adequate nutritional quality (especially CP), and forage quantity, resulting in optimum physiological condition for onset of calving and return to estrus. However, further study is needed for a better understanding of the factors affecting physiological responses of animals to help ensure effective use of forage kochia to improve reproductive performance.

6. Conclusions

K. prostrata is a valuable forage plant for sheep and goats in the temperate, semiarid and arid regions of central Asia. In these areas, it is known as the “alfalfa of the desert” (Waldron et al., 2005) and “a fattening feed for sheep” (Larin, 1956; Nechaeva, 1985). It is not as common in the semiarid western U.S., but it is recommended for reclaiming degraded rangelands, in part because of its competitive advantage over cheatgrass, as well as its value as forage for cattle, sheep and wildlife. It is extremely drought and salt tolerant, often growing in extremely harsh environmental conditions that preempt other plant species. Research and experience have shown that forage kochia is a very palatable and nutritious shrub, especially during the fall and winter when nutritional quality of other plants is low. Its nutritional characteristics include CP levels above 70 g/kg needed for ruminant animals, acceptable fiber levels, low tannins and oxalates, and improved digestion kinetics when mixed with the low quality diets common during late summer, fall, and winter months. Forage kochia has the potential to improve the sustainability of small and large ruminant production in areas that are threatened with extended drought and increasing salinity.

References

- Adams, D.C., Clark, R.T., Coady, S.A., Lamb, J.B., Nielsen, M.K., 1994. Extended grazing systems for improving economic returns from Nebraska sandhills cow/calf operations. *J. Range Manag.* 47, 258–263.
- Alimov, E., Amirkhanov, Zh., 1980. Breeding of *Kochia prostrata* Schrad. in deserts of southeastern Kazakhstan. *Probl. Desert Dev.* 3, 57–60.
- Allison, M.J., Cook, H.M., Dawson, K.A., 1981. Selection of oxalate-degrading rumen bacteria in continuous cultures. *J. Anim. Sci.* 53, 810–816.

- Balyan, G.A., 1972. Prostrate summer cypress and its culture in Kirghizia. Isdatel'stvo, Frunze, Kirghizistan. Translated from Russian, 1979. Published for the U.S. Dept. of Agriculture and the National Science Foundation by the Al Ahram Center for Scientific Translation, Springfield, VA. Available from National Tech. Information Service. 294 pp.
- Ben Salem, H., Smith, T., 2008. Feeding strategies to increase small ruminant production in dry environments. *Small Rumin. Res.* 77, 174–194.
- Burrows, G.E., Horn, G.W., McNew, R.W., Croy, L.L., Keeton, R.D., Kyle, J., 1987. The prophylactic effect of corn supplementation on experimental nitrate intoxication in cattle. *J. Anim. Sci.* 64, 1682–1689.
- Burrows, G.E., Tyrl, R.J., 2001. Toxic Plants of North America. Iowa State Univ. Press, Ames, IA, pp. 351–355.
- Clay, B.R., Edwards, W.C., Peterson, D.R., 1976. Toxic nitrate accumulation in the sorghums. *Bovine Pract.* 11, 28–32.
- Clements, C.D., Gray, K.J., Young, J.A., 1997. Forage kochia: to seed or not to seed. *Rangelands* 19, 29–31.
- Cochran, R.C., Adams, D.C., Currie, P.O., Knapp, B.W., 1986. Cubed alfalfa hay or cottonseed meal-barley as supplements for beef cows grazing fall-winter range. *J. Range Manag.* 39, 361–364.
- Cook, C.W., 1972. Comparative nutritive values of forbs, grasses, and shrubs. In: McKell, C.M., Blaisdell, P.J., Goodin P.R. (Eds.), *Wildland shrubs. Their biology and utilization*. USDA Forest Serv. Gen. Tech. Rep. INT-1. Ogden, UT, USA, pp. 303–310.
- Cook, C.W., Stoddart, L.A., Harris, L.E., 1953. Effects of grazing intensity upon the nutritive value of range forage. *J. Range Manag.* 6, 51–54.
- Davenport, B.W. 2005. Cattle utilization of forage kochia (*Kochia prostrata*) and its relation to forage quality and plant morphological characteristics. M.S. thesis, Utah State Univ., Logan, UT, USA, 75 pp.
- Davis, A.M., 1979. Forage quality of prostrate kochia compared with 3 browse species. *Agron. J.* 71, 822–824.
- Davis, J.N., Welch, B.L., 1985. Winter preference, nutritive value, and other range use characteristics of *Kochia prostrata* Schrad. *Great Basin Nat.* 45, 778–782.
- DelCurto, T., Olson, K.C., 2000. Physical form of crude protein for supplementation of low-quality roughages. In: *Strategic Supplementation of Beef Cattle Consuming Low-Quality Roughages in the Western United States*. Oregon Exp. Sta. Bull. SB 683, Corvallis, OR, USA, pp. 40–50.
- Donnelly, E.D., Anthony, W.B., 1969. Relationship of tannin, dry matter digestibility and crude protein in *Sericia lesrezeza*. *Crop Sci.* 9, 361–363.
- Durikov, M., 1986. The age-mix of cenopopulations of *Kochia prostrata* (L.) Schard. in agrophytocenoses on the rigdes-takyr complex of the southern districts of the central Kara Kum. *Probl. Desert Dev.* 2, 62–69.
- Durkov, M.Kh., 1990. Structure of cenopopulations and productivity of prostrate summer cypress (*Kochia prostrata* (L.) (Schrad.). *Probl. Desert Dev.* 1, 63–69.
- Forbes, J.M., 1996. Integration of regulatory signals controlling forage intake in ruminants. *J. Anim. Sci.* 74, 3029–3035.
- Francois, L.E., 1976. Salt tolerance of prostrate summer cypress. *Agron. J.* 68, 455–456.
- Freeze, B.S., Willms, W.D., Rode, L., 1999. Economics of maintaining cow condition on fescue prairie in winter. *J. Range Manag.* 52, 113–119.
- Frischknecht, N.C., Ferguson, R.B., 1984. Performance of chenopodiaceae species on processed oil shale. In: Tiedemann, A.R., McArthur, E.D., Romney, E.M., Stutz, H.C., Stevens, R., Johnson, K.L. (Eds.), *Proceedings-Symposium on Biology of Atriplex and Related Chenopods*. May 2–6, 1983, Provo, UT. USDA Forest Serv. Gen. Tech. Rep. INT-172, Ogden, UT, USA, pp. 293–297.
- Gade, A.E., Provenza, F.D., 1986. Nutrition of sheep grazing crested wheatgrass versus crested wheatgrass-shrub pastures during winter. *J. Range Manag.* 39, 527–530.
- Gintzburger, G., Toderich, K.N., Mardonov, B.K., Mahmudov, M.M., 2003. *Rangelands of the Arid and Semi-Arid Zones in Uzbekistan*. CIRAD, ICARDA, Montpellier, France, 426 pp.
- Haferkamp, M.R., Ganskopp, D.C., Marietta, K.L., Knapp, B.W., 1990. Environmental influences on germination of utricles and seedling establishment of 'Immigrant' forage kochia. *J. Range Manag.* 43, 518–522.
- Haliburton, J.C., Edwards, W.C., 1978. Nitrate poisoning in Oklahoma cattle during the winter of 1977–1978. *Vet. Hum. Toxicol.* 20, 401–403.
- Harrison, R.D., Chatterton, N.J., Waldron, B.L., Davenport, B.W., Palazzo, A.J., Horton, W.H., Asay, K.H., 2000. Forage kochia: its compatibility and potential aggressiveness on intermountain rangelands. *Utah Agr. Exp. Stat. Res. Rep.* 162, Utah State Univ., Logan, UT, p. 66. Available at <http://www.ars.usda.gov/Services/docs.htm?docid=17703> (accessed 21.10.08).
- Harrison, R.D., Waldron, B.L., Jensen, K.B., Page, R.J., Monaco, T.A., Horton, W.H., Palazzo, A.J., 2002. Forage kochia helps fight range fires. *Rangelands* 24, 3–7.
- Herbel, C.H., Barnes, R.F., Heady, H.F., Purdy, L.N., 1981. Range research in the Soviet Union. *Rangelands* 3, 61–63.
- Hess, B.W., Park, K.K., Krysl, L.J., Judkins, M.B., McCracken, B.A., Hanks, D.R., 1994. Supplemental protein for beef cattle grazing dormant intermediate wheatgrass pasture: effects on nutrient quality, forage intake, digesta kinetics, grazing behavior, ruminal fermentation, and digestion. *J. Anim. Sci.* 72, 2113–2123.
- Jones, R.J., Seawright, A.A., Little, D.A., 1970. Oxalate poisoning in animals grazing the tropical grass *Setaria sphacelata*. *J. Aust. Inst. Agric. Sci.* 36, 41–43.
- Kashkarov, A.A., Balyan, G.A., 1989. Raising productivity of pastures in the rocky deserts. *Probl. Desert Dev.* 4, 85–88.
- Kitchen, S.G., Monsen, S.B., 2001. Forage kochia seed germination response to storage time and temperature. *J. Range Manag.* 54, 299–306.
- Knipfel, J.E., 1977. Nutritional adequacy of mature Altai wild rye grass and crested wheatgrass, or of alfalfa-wheat straw mixtures for the pregnant ewe. *Can. J. Anim. Sci.* 57, 405–410.
- Koch, D.W., Asay, W., 2002. Forage kochia—a forage with fall and winter grazing potential. University of Wyoming Extension Pamphlet B-1122.5, Univ. of Wyoming, Laramie, Wyoming, USA. Available at <http://ces.uwyo.edu/PUBS/B1122-5.pdf> (accessed 10.11.08).
- Krylova, N.P., 1988. Foreign experience in introducing *Kochia prostrata*. *Probl. Desert Dev.* 6, 11–18.
- Lachko, O.A., 1987. Main features of production and transpiration of *Kochia prostrata* L. (Schrad.) in the northwest Caspian area. *Probl. Desert Dev.* 3, 34–41.
- Larin, I.V., 1956. Pasture economy and meadow cultivation (Translated to English 1962 and published by Israel program for Scientific Translation, Jerusalem), pp. 168–170.
- Lee, B.S., Kim, M.Y., Wang, R.R.-C., Waldron, B.L., 2005. Relationships among 3 *Kochia* species based on PCR-generated molecular sequences and molecular cytogenetics. *Genome* 48, 1104–1115.
- Leonard, E.D., Monaco, T.A., Stark, J.M., Ryel, R.J., 2008. Invasive forb, annual grass, and exotic shrub competition with three sagebrush-steppe growth forms: Acquisition of a spring ¹⁵N tracer. *Invasive Plant Sci. Manag.* 1, 168–177.
- McArthur, E.D., Blauer, A.C., Stevens, R., 1990. Forage kochia competition with cheatgrass in central Utah. In: McArthur, E.D., Romney, E.M., Smith, S.D., Tueller, P.T. (Eds.), *Proceedings-Symposium on Cheatgrass Invasion, Shrub Die-Off, and Other Aspects of Shrub Biology and Management*. April 5–7, 1989, Las Vegas, NV. USDA Forest Serv. Gen. Tech. Rep. INT-276, Ogden, UT, USA, pp. 56–65.
- McArthur, E.D., Sanderson, S.C., Davis, J.N., 1996. Adaptation of forage kochia accessions across an environmental gradient in rush valley, Utah. *Arid Soil Res. Rehabil.* 10, 125–138.
- McCartney, D., Basarab, J.A., Okine, E.K., Baron, V.S., Depalme, A.J., 2004. Alternative fall and winter feeding systems for spring calving beef cows. *Can. J. Anim. Sci.* 84, 511–522.
- McFarland, M.L., Ueckert, D.N., Hartmann, S., Hons, F.M., 1990. Transplanting shrubs for revegetation of salt-affected soils. *Landscape Urban Plann.* 19, 377–381.
- McKell, C.M., 1986. Propagation and establishment of plants on arid saline land. *Reclam. Reveg. Res.* 5, 363–375.
- McKell, C.M., Otsyina, R.M., Malechek, J., 1990. Diets of sheep grazing forage kochia and winterfat mixed grass pastures in late fall. In: McArthur, E.D., Romney, E.M., Smith, S.D., Tueller, P.T. (Eds.), *Proceedings-Symposium on Cheatgrass Invasion, Shrub Die-Off, and Other Aspects of Shrub Biology and Management*. April 5–7, 1989, Las Vegas, NV. USDA Forest Serv. Gen. Tech. Rep. INT-276, Ogden, UT, USA, pp. 310–316.
- McKenzie, R.A., Bell, A.M., Storie, G.J., Keenan, F.J., Cornack, K.M., Grant, S.G., 1988. Acute oxalate poisoning of sheep by buffel grass (*Cenchrus ciliaris*). *Aust. Vet. J.* 65, 26–29.
- Merchen, N.R., 1993. Digestion, absorption, and excretion in ruminants. In: Church, D.C. (Ed.), *The Ruminant Animal: Digestive Physiology and Nutrition*. Waveland Press, Prospect Heights, IL, USA, pp. 172–201.
- Monaco, T.A., Waldron, B.L., Newhall, R.L., Horton, W.H., 2003. Reestablishing perennial vegetation in cheatgrass monocultures. *Rangelands* 25, 26–29.
- Morton, H.L., Haas, R.H., Erickson, L.C., 1959. Oxalate and mineral content of *Halogeton glomeratus*. *Weeds* 7, 255–264.
- Murphy, L.S., Smith, G.E., 1967. Nitrate accumulation in forage crops. *Agron. J.* 59, 171–174.
- National Research Council (NRC), 1996. *Nutrient Requirements of Beef Cattle*, seventh ed. National Academy Press, Washington, DC, USA.
- Nechaeva, N.T., 1985. Description of plants used for vegetative range improvement. In: Nechaeva, N.T. (Ed.), *Improvement of Desert Ranges in Soviet Central Asia*. Harwood Academic Publishers, New York, pp. 55–120.

- Nemati, N., 1977. Comparative palatability of *Atriplex canescens*. J. Range Manag. 30, 368–369.
- Nemati, N., 1986. Pasture improvement and management in arid zones of Iran. J. Arid Environ. 11, 27–35.
- Newhall, R.L., Monaco, T.A., Horton, W.H., Harrison, R.D., Page, R.J., 2004. Rehabilitating salt-desert ecosystems following wildfire and wind erosion. Rangelands 26, 3–7.
- Otsyina, R., McKell, C.M., Van Epps, G., 1982. Use of range shrubs to meet nutrient requirements of sheep grazing on crested wheatgrass during fall and early winter. J. Range Manag. 35, 751–753.
- Pendleton, R.L., Frischknecht, N.C., McArthur, E.D., 1992. Long-Term Survival of 20 Selected Plant Accessions in a Rush Valley, Utah, Planting. USDA Forest Serv. Research Note INT-403, Ogden, UT, USA, p. 7.
- Pope, C.L., McArthur, E.D., 1977. IOPB chromosome number report. Taxon 26, 109.
- Pyankov, V.I., Artyusheva, E.G., Edwards, G.E., Black, C.C., Soltis, P.S., 2001. Phylogenetic analysis of tribe Salsola (Chenopodiaceae) based on ribosomal ITS sequences: implications for the evolution of photosynthesis types. Am. J. Bot. 88, 1189–1198.
- Pyankov, V.I., Vakhrusheva, D.V., Durikov, M.Kh., 1988. Structural-functional characteristics of ecotypes of *Kochia prostrata* (L.) Schrad. in agrophytocenoses of the central Karakum and Kopetdag foothills. Probl. Desert Dev. 1, 67–73.
- Rabbimov, A., 1984. Structure of populations of *Kochia prostrata* (L.) Schrad. var. virescens by indications of economic value. Probl. Desert Dev. 2, 69–73.
- Reed, J.D., 1995. Nutritional toxicology of tannins and related polyphenols in forage legumes. J. Anim. Sci. 73, 1516–1528.
- Romo, J.T., Haferkamp, M.R., 1987. Forage kochia germination response to temperature, water stress, and specific ions. Agron. J. 79, 27–30.
- Rubtsov, M.I., Sagimbaev, R.R., Shakhnov, E.S., Tiran, T.A., Balyan, G.A., 1989. Natural polyploids of prostrate summer cypress and winterfat as initial material. Sov. Agric. Sci. 4, 20–24.
- Shakhnov, E.S., Sagimbaev, R.R., 1982. Spontaneous polyploidy in *Kochia prostrata*. Probl. Desert Dev. 2, 57–60.
- Stevens, R., Van Epps, G.A., 1984. Seeding techniques to improve establishment of forage kochia. In: Tiedemann, A.R., McArthur, E.D., Romney, E.M., Stutz, H.C., Stevens, R., Johnson, K.L. (Eds.), Proc.-Symp. on Biology of *Atriplex* and Related Chenopods. May 2–6, 1983, Provo, UT. USDA Forest Serv. Gen. Tech. Rep. INT-172, Ogden, UT, USA, pp. 269–272.
- Stevens, R., McArthur, E.D., 1990. 'Immigrant' forage kochia competition with halogeton following various seeding techniques. In: McArthur, E.D., Romney, E.M., Smith, S.D., Tueller, P.T. (Eds.), Proceedings-Symposium on Cheatgrass Invasion, Shrub Die-Off, and Other Aspects of Shrub Biology and Management. April 5–7, 1989, Las Vegas, NV. USDA Forest Serv. Gen. Tech. Rep. INT-276, Ogden, UT, USA, pp. 175–180.
- Stevens, R., Jorgensen, K.R., McArthur, E.D., Davis, J.N., 1985. 'Immigrant' forage kochia. Rangelands 7, 22–23.
- Stewart, A., Anderson, V.J., Kitchen, S.G., 2001. 'Immigrant' forage kochia seed viability as impacted by storage methods. J. Range Manag. 54, 396–399.
- Stonecipher, C.A., Olson, K.C., Malachuk, J.C., Carter, D.D., 2004. Intake and digestibility response to forage kochia (*Kochia prostrata*) in a low quality forage diet. In: Proceedings of the Western Section. American Society of Animal Science, Oregon State University, Corvallis, OR, USA, pp. 273–275.
- Van Soest, P.J., 1994. Nutritional Ecology of the Ruminant, second ed. Cornell University Press, Ithaca, NY, USA.
- Villalobos, G., Adams, D.C., Klopfenstein, T.J., Nichols, J.T., Lamb, J.B., 1997. Grass hay as a supplement for grazing cattle. I. Animal performance. J. Range Manag. 50, 351–356.
- Wagner, J.J., Lusby, K.S., Oltjen, J.W., Rakestraw, J., Wetteman, R.P., Walters, L.E., 1988. Carcass composition in mature Hereford cows: estimation and effect on daily metabolizable energy requirement during winter. J. Anim. Sci. 66, 603–612.
- Waldron, B.L., Harrison, R.D., Dzyubenko, N.I., Khusainov, A., Shuvalov, S., Alexanian, S., 2001. *Kochia prostrata* germplasm collection expedition to Kazakhstan. In: McArthur, E.D., Fairbanks, D.J. (Eds.), Proc.-Symp. on Shrubland Ecosystem Genetics and Biodiversity. June 13–15, 2000, Provo, UT. USDA Forest Serv. Gen. Tech. Rep. RMRS-P-21, Ogden, UT, USA, pp. 113–117.
- Waldron, B.L., Harrison, R.D., Rabbimov, A., Mukimov, T.C., Yusupov, S.Y., Tursynova, G., 2005. Forage kochia-Uzbekistan's desert alfalfa. Rangelands 27, 7–12.
- Waldron, B.L., ZoBell, D.R., Olson, K.C., Jensen, K.B., Snyder, D.L., 2006. Stockpiled forage kochia to maintain beef cows during winter. Rangeland Ecol. Manag. 59, 275–284.
- Wall, A.R., Olson, K.C., Stonecipher, C.A., Stuart, M., Maughn, M.A., Malechek, J.C., 2006. Estimation of digesta kinetics of forage kochia and tall wheatgrass using YB and DY when fed alone or mixed together. In: Proc. Western Section, Am. Soc. Anim. Sci. Utah State University, Logan, UT, USA, pp. 48–51.
- Waller, S.S., Britton, C.M., Schmidt, D.K., Stubbendieck, J., Sneva, F.A., 1983. Germination characteristics of two varieties of *Kochia prostrata* (L.) Schrad. J. Range Manag. 36, 242–245.
- Welch, B.L., Davis, J.N., 1984. *In vitro* digestibility of *Kochia prostrata* (L.) Schrad. Great Basin Nat. 44, 296–298.
- West, N.E., 1983. Intermountain salt-desert shrubland. In: West, N.E. (Ed.), Temperate Deserts and Semi-Deserts. Elsevier Scientific Publishing Company, Amsterdam, Netherlands, pp. 375–397.
- Willms, W.D., Rode, L.M., Freeze, B.S., 1993. Winter performance of Hereford cows on fescue prairie and in drylot as influenced by fall grazing. Can. J. Anim. Sci. 73, 881–889.
- Young, J.A., Evans, R.A., Stevens, R., Everett, R.L., 1981. Germination of *Kochia prostrata* seed. Agron. J. 73, 957–961.
- Zadbar, M., Dormanov, D.N., Shariph-abad, H.H., Dorikov, M., Jalilvand, H., 2007. Row distance method of sowing forage kochia, eastern saltwort and winterfat. Pak. J. Biol. Sci. 10, 1571–1579.